ACOUSTIC NOISE CONTROL PLAN

for

ISS PAYLOADS

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D.1.0 INTRODUCTION

Acoustic sound levels within habitable crew areas of the Orbiter and module have been a troublesome issue in past flights where experiments often exceeded specified noise requirements. This has led to crewmember complaints of communication difficulty, concentration problems, sleep interference, headaches, and ringing of ears. Excessive noise has also been attributed as the cause of temporary threshold hearing shifts during short missions and, in several cases, permanent hearing loss.

The Acoustic Noise Control Plan herein presents an approach that, if followed, will preclude acoustic noise problems within the ISS. Payload equipment cannot be deemed qualified for flight until it is shown that its nominal (non-failure) operating modes, location, and configuration(s) over its life onboard the ISS will not acoustically degrade the crew living environment of the element in which it resides.

Toward this objective, this document summarizes the acoustic noise criteria inside the ISS modules, suballocation of the overall criteria, requirements for verifying compliance with criteria, and methods that can be implemented in design and management of the payload equipment to control emitted noise.

Since part of the process of verifying compliance with acoustic noise criteria is the development of a Payload-Unique Noise Control Plan, this document also provides an outline and guidelines for developing this plan. The Payload-Unique Noise Control Plan will outline the procedures, sequence of events, and design developments that will be taken in order to ensure acoustic noise compliance. The intent of this guide is to assist the user to address the design towards acoustic compliance. The items submitted as sample quieting methods are not intended to limit the integrator’s possible solution base. This plan requires tailoring specific to the integrator’s methods of implementation and hardware characteristics.

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D.2.0 ACOUSTIC NOISE ALLOCATION

ISS acoustic noise requirements have been established for an integrated ISS module. The NC-50 noise curve criteria was selected based upon several considerations, notably the following: hearing acuity, speech intelligibility, habitability, safety, productivity, annoyance, and sleep interference. Reference 1 describes the findings that were mandated as the National Aeronautic and Space Administration's requirements for acoustics onboard the ISS.

Since total acoustic noise environment in an ISS module is the sum of all noise contributors, the NC-50 noise criteria must be suballocated to the noise-making components within the ISS module. Subsections below discuss suballocation of the module noise criteria to individual racks, to components in a rack, and to non-rack components.

D.2.1 INTEGRATED RACK ALLOCATION

The NC50 noise criteria, applicable to an ISS module, has been suballocated in Section 3.12.3.3 of the Pressurized Payloads IRD (Reference 2) to individual components in the module (e.g., integrated rack). This suballocation of the acoustic noise environment to each integrated rack shall be instituted as design requirements and shall apply to the composite noise level of the noisiest configuration of simultaneously-operating components within the rack (including any supporting adjunct active portable equipment operated outside the integrated rack but within the ISS module).

Acoustic noise limits are defined in Reference 2 for two types of noise sources: (1) Continuous Noise Source and (2) Intermittent Noise Source. To reiterate the definitions, an integrated rack that operates for more than eight hours in a 24 hour period and generates an A-weighted sound pressure level (SPL) equal to or in excess of 37 decibels (dBA) measured at 0.6 meter distance from the noisiest part of the rack is a Continuous Noise Source. An integrated rack which operates for less than eight hours in any one 24 hour period and generates an A-weighted sound pressure level (SPL) equal to or in excess of 37 dBA measured at 0.6 meter distance from the noisiest part of the rack, is an Intermittent Noise Source. Further information is given in Section 3.12.3.3 of the IRD concerning acoustic noise limits for hardware that exhibits both Continuous and Intermittent noise characteristics.

D.2.2 SUBRACK ALLOCATION

Acoustic noise limits, provided in Section 3.12.3.3 of the IRD for individual integrated racks, shall be further suballocated to subrack components by the rack integrator such that the acoustic noise of the composite rack will not exceed limits defined in the IRD.

D.2.3 NON-RACK ALLOCATION

Acoustic noise limits of non-rack components, operated independently of and outside the integrated rack, are allocated the same limits imposed for an integrated rack. (Reference Section 3.12.3.3 of the IRD) Note that any external adjunct equipment that is operated in support of the integrated rack is included with the integrated rack discussed in Section D.2.1.

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D.3.0 ACOUSTIC NOISE VERIFICATION

Acoustic noise verification of ISS Payloads is a multi-stage process, with data deliveries required at specific points along the path. Section D.3.1 discusses the four primary verification stages. Three of these stages require data inputs to the Element Integrator. Section D.3.2 delineates the verification data required and the schedule for submittal. Section D.3.3 provides additional technical details about the verification data required.

D.3.1 VERIFICATION STAGES

The first stage of the verification process begins at the start of hardware design development. Many times, acoustic noise compatibility is not addressed by hardware developers until the certification testing phase (i.e., final verification stage). This is likely to result in hardware that will not meet specified acoustic requirements. To preclude this from occurring, acoustic noise criteria should be included in the hardware design specifications. It is inherently easier to design for “low noise” rather than trying to “seal” the noise from entering the crew compartment. No formal data delivery is required for the first stage; however, plans and actions implemented in the first stage are included in the data delivery for the second stage.

The second stage of verification is the development and submittal of a Payload-Unique Acoustic Noise Control Plan for the integrated rack or ancillary equipment. The Acoustic Noise Control Plan shall provide the rack integrator’s (or adjunct equipment developer’s) plan for controlling acoustic noise emissions to ensure that final verification requirements are met. The plan shall also describe acoustic noise data that will be submitted for verification and define analytical and test methodology that will be used to obtain verification data. If an analytical process will be used in obtaining verification data, the process for test-validating the analysis procedure must be defined. Section D.5.0 herein provides guidelines for developing the Payload-Unique Acoustic Noise Control Plan.

The third stage of verification is the development of preliminary acoustic noise emission data. At this stage, the acoustic noise data should represent the best data available that can be obtained analytically via estimation or calculation, obtained from developmental testing, or obtained using measured data from similar hardware. The preliminary data should provide predictions of the noise emitted from the worst-case continuous noise source and from the worst-case intermittent noise source. Formal submittal of an Acoustic Noise Report is not required at this stage. The data shall, however, be included in the Payload-Unique ICD prior to its baseline.

The fourth stage of verification is the submittal of final data for flight certification that acoustic noise verification requirements have been met. Information submitted in the final Acoustic Analysis Report defines acoustic noise sources, summarizes the acoustic noise emission from the integrated rack (or adjunct equipment), describes tests performed to measure acoustic noise emissions, describes analytical procedures used in deriving acoustic noise emissions, and documents compatibility with acoustic requirements. Section D.3.2.3 herein provides additional details about contents and schedule for the final Acoustic Analysis Report. Section D.3.3 provides information concerning technical requirements for the final verification data.

D.3.2 VERIFICATION DATA REQUIREMENTS/SCHEDULE

Acoustic data submittals are required for three of the four verification stages discussed in Section D.3.1. Sections D.3.2.1 through D.3.2.3 discuss the data requirements and schedule for each of the three submittals.

D.3.2.1 PAYLOAD-UNIQUE ACOUSTIC NOISE CONTROL PLAN SUBMITTAL

The first report that must be submitted is a Payload-Unique Acoustic Noise Control Plan, required 26 months prior to launch. The Payload-Unique Acoustic Noise Control Plan defines the rack integrator's (or adjunct equipment supplier's) plan for ensuring/verifying that the integrated rack or adjunct equipment will meet acoustic noise requirements specified in the IRD. The plan should describe the acoustic noise system, define applicable requirements, define the methodology for suballocation of requirements, identify the technical approach to verification (e.g., testing, analysis), describe the approach to validating analytical methods (if applicable), describe testing methodology, etc.

The plan should also identify the process that will be used to control acoustic noise of subrack elements. This includes a recovery plan (see paragraph D.5.1.5 for details) that will be implemented if acoustic noise emissions exceed allocated noise requirements.

Section D.5.0 provides more specific details about the development of a Payload-Unique Acoustic Noise Control Plan.

D.3.2.2 PRELIMINARY ACOUSTIC ANALYSIS DATA

The second data item that must be submitted is the inclusion of preliminary acoustic noise data into the Payload Unique ICD. This data shall be included in the Payload-Unique ICD prior to its baselining, no later than 20 months prior to launch. Preliminary data included in the Payload-Unique ICD shall include noise emitted from the worst-case continuous noise source and from the worst-case intermittent noise source. Data for continuous-type noise sources shall be SPL data as a function of the octave-band frequencies: 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz. Linear overall and A-weighted overall levels shall also be provided. Data for intermittent-type noise sources shall be the A-weighted overall levels. SPL data for the preliminary report are usually obtained from the best source available and may be obtained from developmental testing, previous testing of similar hardware, or from analysis.

Data in the Payload-Unique ICD provides a preliminary acoustic compatibility assessment of whether the integrated rack or adjunct equipment meets the IRD noise requirements. The data also will be used by the Element Integrator to perform a preliminary acoustic noise analysis of the integrated module.

It is important that the preliminary acoustic noise data provided in the Payload-Unique ICD accurately represent best-available noise level predictions, even if these levels indicate that noise limits will be exceeded. An exceedance will alert the Element Integrator to a potential problem. Then the Element Integrator can use information from the preliminary acoustic analysis data to identify, review, and research possible noise reduction measures. The information also can be used to prevent co-location of noisy equipment; thus, reducing noise source concentration.

If the preliminary acoustic noise data suggests that acoustic noise limits specified by the IRD will be exceeded, a recovery plan shall be included in the Payload-Unique ICD. Reference to a recovery plan in the Payload-Unique Noise Control Plan could be used to satisfy this.

D.3.2.3 FINAL ACOUSTIC VERIFICATION REPORT

The third report that must be submitted, required 12 months prior to launch, is the Final Acoustic Verification Report. This report will (1) verify that the integrated rack or adjunct equipment meets specified acoustic requirements in the IRD and (2) provide data that can be used by the Element Integrator to perform a final acoustic noise analysis of the integrated module.

The Final Acoustic Verification Report should identify significant noise sources by type of noise (continuous or intermittent); provide the geometric location of noise sources; and provide Sound Pressure Level (SPL) data for each noise source, noise type and operational mode. Operational data such as time-line schedules for each significant noise source shall be provided in the report. A list shall also be provided identifying independently-operated equipment, dependent hardware, and adjunct hardware. Data shall be in sufficient detail to allow definition of the major noise contributors (e.g., data shall be provided for individual subrack elements within an integrated rack).

ISPRs using the Vacuum Exhaust System (VES) shall list their exhaust requirements in terms of volume, pressure (max and nominal), flowrate (max and duration), and time-to-exhaust-to-vacuum requirements. The vacuum event information shall also include a description of how the vacuum exhaust events are to be timelined, whether they correspond to crew activity, or are based upon self-activation or telescience activities.

The Final Acoustic Verification Report also should provide information about the process used to obtain final verification data. Acoustic noise testing is the preferred method of obtaining final verification data, but in some cases a test-verified analytical method can be used. (See Section D.3.3) Information that must be included in the Final Acoustic Verification Report is described below for each of the two methods of obtaining data. If acoustic data in the final report are obtained via testing, the report shall include the following:

1. <u>Test Set-Up/Test Room Characteristics</u> - Describe (preferably via sketches) the test set-up including the type of room used in performing the tests. If a “quiet room” is used, document the test set-up/test room characteristics. (“quiet” room is defined in Section D.3.3.1.1) This should include a description of the test configuration (including room dimensions, description of room surfaces, and test article layout), identification of test-article loudest radiating surface, identification of test-article surfaces exposed to habitable areas, equipment location, and microphone location.

2. <u>Acoustic Noise Emission Data</u> - Sound Pressure Level (SPL) data shall be provided for the loudest point on each side of the integrated rack or adjunct equipment. This information shall be provided for each operational mode for which acoustic data are collected (See Item 1 of Section D.3.3.1.2). Data for continuous noise sources shall be SPL data measured at the octave-band frequencies: 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz. The linear overall and A-weighted overall readings should also be provided. Data for intermittent noise sources shall be the A-weighted overall readings.

3. <u>Background Noise Measurement Data</u> - Background noise measurement data corresponding

to the acoustic noise measurements from Item 2 above shall be provided.

If SPL data are obtained using a test-verified analytical method, the technical approach shall be documented in the report. The report shall also describe how the analytical method is test-validated. Data shall be provided for each operational mode identified. For continuous noise sources, the data shall include SPL data as a function of octave-band frequencies: 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz. The linear overall and A-weighted overall levels should also be provided. Data for intermittent noise sources shall be the A-weighted overall levels.

D.3.3 TECHNICAL REQUIREMENTS FOR VERIFICATION DATA

Measured test data from actual flight hardware is the preferred source for acoustic noise verification data. It is recognized, however, that measured test data may not be available in some cases. For example, performing acoustic noise tests for integrated racks whose complements will change on-orbit may not be practical. Thus, acoustic analysis is acceptable for these exceptions, subject to the requirements of Section D.3.3.2 below. Technical requirements for obtaining data via testing are discussed in Section D.3.3.1 below.

D.3.3.1 VERIFICATION DATA VIA ACOUSTIC NOISE TEST

The objective of acoustic noise testing is to determine the noise emission characteristics of an integrated rack (or adjunct equipment) during all on-orbit operational phases. The integrity of the test is highly dependent upon the quality of the acoustic test conducted. An improperly performed test provides little-or-no useful data that can be used to determine the integrated module acoustic noise environment. The purpose of this section is to provide technical guidelines for performing acoustic emission testing.

Sound Pressure Level (SPL) tests provide the standard data required for verification. When integrated racks (or adjunct equipment) are unable to meet specified SPL levels, Sound Power Level (PWL) test data will be required. Technical guidelines are given below for both SPL and PWL testing.

D.3.3.1.1 SOUND PRESSURE LEVEL TESTING

D.3.3.1.1.1 TEST ROOM REQUIREMENTS

Acoustic noise emission tests shall be performed either in an anechoic chamber or a qualified reverberant quiet room. A “quiet” room has background acoustic noise environment at least 3 dB lower

that the test article. A qualified reverberant room is one in which the reverberant characteristics are known.

If a “quiet” room is selected as the test room, it should have as little background noise as possible. The background noise should preferably be at least 15 dB, below the noise limit specified for the test article (i.e., limits discussed in Section 2 herein). If this cannot be attained, the equipment to be measured should emit at least 3 dB greater noise than the background noise levels. If this condition can not be achieved, it is acceptable if the test article noise levels plus the background noise levels are below the maximum allowable values provided in the acoustical specification. Otherwise, the flight equipment noise is not measurable. For many laboratory environments, additional measures to reduce the background noise will probably be required, such as turning off air conditioning equipment and/or using sound absorbing partitions to create a better background environment. The background noise restrictions apply in all octave bands.

Room dimensions should be as large as possible and the inner surfaces of the walls, floor, and ceiling should be as acoustically-absorbent as possible. The width of the room should be at least 6 meters and in all cases at least 4 meters. Acoustically-reflective articles (e.g., bookcases, tables, filing cabinets) should be removed from the room or placed at least 3 meters from the test article.

Ground Support Equipment (GSE) that produce noise should be well separated from the flight hardware during the test (preferably located outside the test facility). If the GSE is in the test area, it should be operating during the background noise measurements.

D.3.3.1.1.2 TEST OPERATION

To obtain accurate and meaningful data, acoustic noise emission tests shall be performed with the test article configured and operating in all operational modes that will occur on on-orbit and that result in significant noise emission. Also, operating voltage should be the same as on-orbit.

The test article should be placed on a small table or stand (about one meter high) near the center (but not exactly in the center) of the test room. It should be oriented so that the test article surface is flush with the edge of the test stand and is oriented so that the test article surface is not parallel with any of the room walls.

The first test to be performed is to measure and record the background noise. This will verify that the background noise requirements of Section 3.3.1.1 are met. Background noise data shall be measured in each of eight octave bands: 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz.

After verifying adequate background levels, the following sequence of tests should be performed to measure acoustic noise emission. These tests shall be performed using a Type I Sound Level Meter (SLM) that has calibrated within the previous 12 months.

1. With the test article operating in a to-be-flown configuration, measure A-weighted overall acoustic emission around all outer surfaces (about 0.6 meter from the surface) to locate the noisiest point on each surface.

2. Record acoustic noise emission from the noisiest point on each surface at 0.6 meter from the surface. If the noise source is continuous-type, Sound Pressure Level (SPL) data shall be recorded in each of eight octave bands: 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz. This data will be used for variant rack configuration analyses. Verification of each rack (or adjunct equipment) is based upon the noisiest location on a surface adjacent to the crew environment. This data should be measured using linear (no weighting or filtering) response. If the noise source is intermittent-type, only the A-weighted overall data is required.

3. After completion of Step 2, switch the test article off and record the background noise with the SLM ranged at the same full-scale settings used in Step 2. It is not necessary that these

background noise measurements be accurate, but are performed to determine how much electronic and acoustic background exist at the settings used when making measurements of the test article.

D.3.3.1.2 SOUND POWER LEVEL TESTING

Sound Power Level testing, performed to determine the strength of the sound source, can be performed using one of several methods, including:

- Reverberation Chamber Testing
- Anechoic Chamber Testing
- Sound Intensity Testing

In general, sound power testing is more involved than sound pressure testing. For Example, sound power testing requires numerous measurements from microphones at predetermined locations on an imaginary "test surface" located away from but surrounding the sound source. Requirements for "test surface" location and number of microphones vary for each method. Therefore, each of the three methods and their associated "test surface" requirements will be discussed separately. The decision as to which method to use for performing PWL testing will depend upon: accessibility of the accepted hardware, cost, and degree of difficulty in conducting the test.

Discussion of each method includes a brief description of the method, a brief summary of requirements/guidelines, and a list of references that provide additional details for the test method.

In addition to references that apply specifically to one of the three test methods, other references of general interest include References "4" through "7". Note that Reference "4", Chapter 6 describes analytical aspects of Sound Power Level Measurements.

D.3.3.1.2.1 REVERBERATION CHAMBER TESTING

A reverberation chamber (generally a laboratory-grade reverberant room) is characterized as a room where all boundaries are hard and the reverberant sound field extends over nearly the entire room volume. The room shape should meet specified requirements and the total room volume required is determined by minimum third-octave center-frequency to be measured.

Testing can be performed either of two ways: (1) by the Comparison Method where the test article noise is compared to a reference source (i.e., calibrated power level noise source) or (2) by the Absolute Method where the sound-absorbing properties of the test room, measured for each frequency band, are used to determine sound power.

Definition of the "test surface" and measurement locations on the surface is a function of test room volume, wavelength of the sound, and accuracy desired.

Since the reverberation method is based on the premise that a diffuse (reverberant) sound field is present, sound directivity is not an issue. This results in an advantage for the reverberation chamber test method, namely that fewer microphone measurements are required. Thus, use of a reverberation chamber is the quickest method of obtaining sound power level data.

References "4" and "8" through "10" provide additional information about sound power testing in reverberation rooms.

D.3.3.1.2.2 ANECHOIC CHAMBER TESTING

An anechoic chamber is characterized as a room where boundaries are highly absorbent and the free-field region (i.e., region free of reverberation) extends almost to the absorbent boundary. The chamber is a semi-anechoic room if the floor is hard and other surfaces are highly absorbent. This is referred to as Hemispherical Space. The chamber is an anechoic room if all surfaces are highly absorbent.

The "test surface" is a hemisphere or sphere centered on the noise source. The number and location of measurement points needed depend on the accuracy required and the directivity characteristics of the noise.

An advantage of the anechoic chamber test method is that a more complete definition of the noise emission field can be obtained that includes both sound power and sound directivity characteristics. As an example, sound directivity data can be used to characterize noise emission from an integrated rack where the noise emitted from the sides of the rack differs from that emitted from the front of the rack.

References "4" and "11" provide additional information about sound testing in anechoic and semi-anechoic rooms.

D.3.3.1.2.3 SOUND INTENSITY TESTING

Sound intensity measurements are performed using a sound intensity probe that measures sound pressure at two points separated by a small distance. The sound intensity probe consists of two microphones separated by a spacer, where spacer thickness is determined by frequency range of the noise measurements.

The "test surface" can be a box, a hemisphere, or a shape that approximates the shape of the test article. Advantages of the sound intensity test method are that (1) background noise does not affect the total sound power measurement and (2) knowledge of the acoustic properties of the test room is not necessary. References "4", "12" and "13" provide additional information about sound intensity testing.

D.3.3.2 VERIFICATION DATA VIA ANALYSIS

Data produced by acoustic analysis may be used for preliminary verification and for final verification of integrated racks where it is not feasible to perform acoustic noise emission tests of an integrated rack. A rack analysis must model the rack's acoustic configuration in detail. The output of the analysis shall predict the noise contribution to the crew environment for each surface that is exposed to the crew environment. The analysis and input data should be sufficiently detailed such that alterations of the configuration could be predicted within a defined level of tolerance. The integrated rack acoustic analysis shall list the possible error tolerance inherent in the analysis. To account for possible error tolerance, the overall design goal for the total integrated rack acoustic noise emission should be set at a value below the requirement (-3 dB for example).

When analysis is used to produce acoustic noise data for final verification, the analysis shall be performed using a test-correlated analytical model or some other test-verified methodology. Figure 4.3.12.3.3.1-1 of the IRD provides a typical flow for the process of developing a test-correlated model. An example of an “other test-verified methodology” could include an analytical process for combining measured sound power levels from multiple subrack components with rack subsystem noise to analytically predict the composite SPL noise emission for the integrated rack. One approach to accomplishing this would be to analytically compute/combine the emitted sound pressure levels from the various sound power sources, applying noise absorption and directivity factors as applicable to the integrated rack. Such an approach would require test correlation of the noise absorption characteristics of the rack and test correlation of the effects of the integrated rack on directivity of the noise from the various noise sources.

D.4.0 ACOUSTIC NOISE CONTROL

Acoustic noise systems can be described as consisting of three components - sources, transmission paths, and receivers. Since receivers consist of the crew and other payloads, control of acoustic noise must be implemented for the sources and transmission paths. Furthermore, reduction of noise levels at the source is generally the preferred method of noise control with the treatment of transmission paths considered a secondary method. Controls are best implemented via design and operational management applied at the beginning of hardware development. Due to weight and space constraints, the easiest manner of developing quiet hardware requires selecting and designing with quiet operation in mind. It is inherently easier to design “quiet” rather that cover and seal the noise away from the crew environment. Specific suggestions for accomplishing noise control via hardware design and operational control are given below. (See Reference 3 for additional details)

D.4.1 HARDWARE DESIGN TECHNIQUE FOR NOISE CONTROL

D.4.1.1 CONTROL OF ACOUSTIC NOISE SOURCES

Mechanical systems involving moving parts (e.g., motors, pumps, fans) or fluid flow systems are usual sources for acoustic noise generation. Thus, noise emission from these sources can be reduced through judicious selection of components and the proper design of fluid systems.

D.4.1.1.1 SELECTION OF LOW-NOISE-LEVEL COMPONENTS

Motors, pumps, and fans should be purchased from vendors that certify the balance “grade” and noise criterion of their equipment. These components should include proper balancing and use of precision bearings. Also, rotating equipment should be used instead of reciprocating equipment.

Equipment items that have multiple operating speeds should be selected. Furthermore they should be controllable through use of speed controllers, rpm monitoring, or thermally-activated speed control.

Ventilation fans should be selected based on the number of blades and operating speed to avoid resonance excitation in fan support structures. A larger number of blades will create higher excitation frequencies, which are easier to control. In general, centrifugal fans with airfoil blades create lower acoustic levels than other fan wheel designs. Also, fan blades constructed from plastic material have been observed to be less noisy than blades made of metal.

Alignment functions and power transmission are often controlled by the meshing of gears or use of chains. Alternate, quieter methods of motion and power transmission can be designed, using various types of belts.

D.4.1.1.2 FLUID SYSTEM DESIGN FOR LOW NOISE

In addition to the selection of low-noise-source components such as motors, pumps, and fans discussed in the previous section, acoustic noise emission from fluid systems can be reduced by designing fluid systems that have low flow velocities and by avoiding large pressure drops in fluid or gas systems.

Use multiple speed pumps to control fluid flow instead of throttling. Throttling tends to induce greater flow noise.

Specify fans that operate in their optimum range and application. (i.e., Do not use a fan designed to move high flowrates through small avionics areas when there is an open plenum area that would allow use of a larger diameter fan turning at much lower speeds.)

Locate fans away from surface panels. This allows the use of duct muffling devices that can absorb noise without affecting flow or delta-P. Also, a fan located near the surface can cause turbulent air currents which, passing through a screen, may cause greater noise than the fan itself.

Other design options for reducing the transmission of acoustic noise from fluid systems are discussed below in Section D.4.1.3.

D.4.1.2 CONTROL OF NOISE TRANSMISSION

Two types of acoustic noise transmission occur: Structureborne and airborne. Complex situations may arise where airborne noise is propagated by structureborne vibration and reradiated into an airspace. Control of this situation involves both attenuating the structureborne transmission path and minimizing structural radiation efficiency.

D.4.1.2.1 CONTROL OF STRUCTUREBORNE NOISE TRANSMISSION

The first order of reducing structureborne acoustic noise transmission is to isolate noise-source components and any associated piping or ducting from their structural support. The second most important item is to design resonant-free support structures by modifying structural stiffness, resonances, damping, and structural coupling. Problem resonances can appear in the form of local panel vibration modes, piping or ductwork vibration modes, or primary structure vibration modes. Primary structure vibration modes are defined as resonances that involve motion of a major portion of the primary support structure. Panel and piping/ductwork vibration modes generally involve motion only in local areas.

When problem resonances cannot be avoided, damping treatments may be applied. Damping treatments include resilient mounts between equipment or piping/ductwork and primary structure or treatment applied to surfaces of structural members. Resilient mounts can be a simple sheet or block of viscoelastic material between equipment or piping/ductwork and its support structure or they can be more complex isolation mounts. Treatment to structural members, which is especially effective for local panel vibration, can range from simple thin coatings of viscoelastic materials to multilayered constrained layer treatments.

Most damping treatments perform more effectively at higher frequencies. Thus, resonance avoidance design and damping treatments work well together when support structures are designed to shift problem resonance higher in frequency.

D.4.1.2.2 CONTROL OF AIRBORNE NOISE TRANSMISSION

Airborne noise transmission from payloads aboard the ISS can be controlled by enclosing the source, modification of ducts and interior spaces, or moving the source as far as possible from habitable areas. As an example of the latter, if the front surface of a rack is exposed to a habitable area, locate the noise source at the rear of the rack. This results in longer transmission paths and therefore, more losses of energy.

A properly-designed structure to enclose an acoustic source inherently attenuates the acoustic noise transmitted outside the enclosure. Enclosures designed to attenuate acoustic noise should include attention to many details including: stiffener placement, penetrations, enclosure isolation, and interior geometry. Rib-stiffened panels should be used carefully since sound tends to radiate from structural discontinuities in a panel, such as a rib-stiffened interface. Penetrations in enclosures for cables or pipes should be kept to a minimum. Penetrating pipes or cables should be as flexible as possible to avoid creating flanking paths. The enclosure itself should be mechanically isolated from internal noise sources. Enclosure interior surfaces should ideally be at least a quarter wavelength away from noise-source-surfaces, at the lowest frequency at which attenuation is desired.

Adding absorptive liner materials within an enclosure increases acoustic absorption within the enclosure, thus, reducing acoustic energy and noise. Modification to alter the enclosure reverberation characteristics also may be used to reduce acoustic noise.

Airborne acoustic noise via reradiation of noise from structureborne vibration is controlled by minimizing radiation efficiency. This can be accomplished using the avoidance of resonance frequencies and damping treatment methods discussed in Section D.4.1.2.1

Air ducts can be significant acoustic noise transmission paths. Constructing air ducts with internal absorptive material or silencers can attenuate propagation of noise down the duct. Both upstream and downstream ductwork should be analyzed and treated as appropriate. Airborne noise also is generated at diffusers and grilles. Lowering airflow velocity reduces this effect. High relative airflow velocities should be avoided in mixing zones where airstreams enter regions of relatively still air.

D.4.1.3 ANALYSIS UNCERTAINTY

Analytical methods are available to develop estimates of the acoustic noise emitted. These include acoustic modeling and other analytical equations that calculate noise emission from a sound power level source based on absorption of sound, reverberant characteristics, and sound directivity. However, analysis tools are limited to working in the ideal world and there have been many cases where analysis has under-estimated actual levels. Therefore, for acoustic noise analysis in early stages of hardware development or when analysis is used to establish design limits, an error tolerance factor should be applied to the analysis results or acoustic noise specification (-3 dB for example). If the analysis is performed using a test-validated process, a lower error tolerance factor could be applied.

Elimination of analysis uncertainty and the establishment of a successful acoustic noise program requires an energetic measurement program. As the design process proceeds from the design phase into fabrication, measured data should be obtained and substituted for estimated or calculated data.

D.4.2 OPERATIONAL TECHNIQUES FOR NOISE CONTROL

D.4.2.1 TIMELINE MANAGEMENT

Rescheduling science operations to prevent two (or more) noisy hardware items from operating simultaneously will result in reduced noise emission. Determine preliminary/updated timeline schedules for ISPR operation with respect to noise emissions. Providing this data to the Element Integrator via will allow scheduling overall module operations to minimize acoustic noise.

D.4.2.2 OPERATING PARAMETER MANAGEMENT

Operation of equipment items which have multiple operating speeds (e.g., fans, pumps) can be used to control acoustic noise emission. Control can be applied in two ways: (1) by using worst-case operating characteristics in the noise budget allocation or (2) operate equipment at speeds that minimize noise emission. Operating voltage is usually a significant parameter in the noise emission of fans and rotating equipment. Reducing operating voltage to the minimum level required can significantly reduce noise emission. Also, pumps should not be operated near speeds corresponding to pump shaft resonant frequencies.

Setting cooling devices to less strict temperature limits can also be used to abate noise emission. Limits that are more strict than needed causes extra duty cycles of operation.

D.4.2.3 EQUIPMENT LOCATION

Provide physical separation of noisy hardware items that must operate concurrently. Since a portion of the emitted acoustic noise is a function of distance from the source, this will reduce the noise environment at a given point.

D.5.0 GUIDELINES FOR DEVELOPMENT OF A PAYLOAD-UNIQUE NOISE CONTROL PLAN

As defined in Section D.3.2.1, the rack integrator or adjunct equipment provider is required to develop and submit a Payload-Unique Acoustic Noise Control Plan. Guidelines are provided in the following subsections for development of the information required in the plan. This includes defining the technical contents of a typical plan and defining the approval process.

D.5.1 TECHNICAL CONTENT

The plan should define the approach that the rack integrator (or adjunct equipment supplier) will take to ensure/verify that the integrated rack or adjunct equipment meets specified acoustic noise requirements. In general, the plan will describe the system in terms of various noise sources, define applicable requirements, define the suballocation of requirements, describe how verification data will be obtained, describe how the data will be documented, and describe the general process for controlling noise.

D.5.1.1 SYSTEM DESCRIPTION

The acoustic system(s) that are covered by the plan should be described. The system description should define the subelements comprising the acoustic system and define who is responsible for providing acoustic data for the final verification of each subelement. Description of the acoustic system also should define the type of noise emitted for the subelement hardware (i.e., continuous, intermittent). If a potential acoustic noise problem is known that could interfere with another hardware item operation or its science goals, the interference should be described. Use of the Vacuum Exhaust System by an integrated rack represents a potential significant noise source. Thus, use of the VES should be described in terms of volume, pressure (max and nominal), flowrate (max and duration), and time to exhaust. The system description should define the hardware system configuration. (Figures should be provided if possible, particularly for integrated-rack systems).

D.5.1.2 REQUIREMENTS DEFINITIONS

A Payload-Unique Acoustic Noise Control Plan should define the applicable acoustic noise environment that will be used as limits in hardware design/development and imposed as verification requirements. These noise limits include the applicable environments from the Pressurized Payloads IRD as well as those levied on subrack payloads via the suballocation process. The plan should describe the process used to suballocate integrated rack acoustic noise limits to individual subrack payloads.

D.5.1.3 METHOD FOR OBTAINING VERIFICATION DATA

One of the most important requirements for the contents of the plan is to define how data that will be used for final verification will be obtained (i.e., acoustic noise testing, acoustic analysis). Acoustic noise testing is the preferred method of obtaining final verification data. This includes acoustic testing of an integrated rack operating in its worst-case on-orbit acoustic noise configuration. In some situations, acoustic testing of an on-orbit configuration may not be possible. (For example, when subrack payload equipment will be changed out on-orbit.) In such cases acoustic analysis may be used to analytically combine acoustic data measured for subrack equipment. The analysis process, however, shall be test-validated.

The type of information that should be provided about the process for obtaining data varies, depending on whether test or analysis is used to obtain data.

D.5.1.3.1 DESCRIPTION OF TEST METHODS

If acoustic noise data is to be obtained by acoustic noise emission testing, the Payload-Unique Acoustic Noise Control Plan should describe the acoustic testing process. The description should include:

1. Description of test facility. Includes type of facility (e.g., anechoic, “quiet room”), dimensions of test room, and acoustic properties of test room. (If test facility information is unknown, a description of the requirements that will be levied for the test facility can be described in lieu of the test facility description.)

2. Identification of acoustic noise measuring devices. Includes a definition of acoustic noise measuring equipment that will be used for tests (or a description of requirements that will be levied).

3. Description of test article configuration. This should define all of the on-orbit configurations for the test article(s) that generate significant noise, identify which of the configurations will be tested, and provide rationale or selection process if not all are selected for test.

4. Summary of the Acoustic Noise Test Plan/Procedure. This should provide the basic approach of how testing will be performed, where measurements will be made, and a description of the data that will be measured.

D.5.1.3.2 DESCRIPTION OF ANALYSIS METHOD

If a test-validated analytical process is to be used to obtain integrated rack acoustic noise emission using measured data for subrack equipment, the Payload-Unique Acoustic Noise Control Plan shall define the analytical process that will be used. The description of the analysis method shall discuss the technical approach and describe the process of test-validation for the approach.

D.5.1.3.2.1 TECHNICAL APPROACH

A detailed description of the technical approach to the analytical process shall be provided. This should include the identification of acoustic analysis software used in modeling. For approaches not using acoustic modeling, the approach and details of the analysis methodology shall be provided.

D.5.1.3.2.2 TEST-VALIDATION OF TECHNICAL APPROACH

Section 4.3.12.3.3 of the IRD (Reference 1) requires test-correlation of any analytical process used to obtained acoustic verification data. This includes test-correlation of acoustic analysis models or other approved analysis methods.

The Payload-Unique Acoustic Noise Control Plan should either provide evidence that a test-correlated analytical process is in place or provide a description of the process that will be used to test-correlate the proposed analysis procedure.

D.5.1.4 REPORTING PROCESS

To ensure that preliminary and final acoustic noise data will meet the needs of the Element Integrator, the Payload-Unique Verification Plan should include a description and format of data that will be included in the Acoustic Noise Verification Report.

D.5.1.5 NOISE CONTROL PROCESS

The Payload-Unique Verification Plan should describe the basic process that will be used for controlling acoustic noise emission. This includes controls placed on hardware development, such as plans for incorporation of acoustic noise criteria in hardware design specifications. Also, controllable design and operational factors such as those defined in Section D.4 herein are other examples.

Another aspect of the Acoustic Noise Control Plan is the rack integrator's (or adjunct equipment provider's) recovery plan (see paragraph D.5.1.5 for details) if acoustic noise emissions exceed specified limits. The recovery plan should include the case where preliminary analysis results predict that specified limits may be exceeded and the case where final verification shows exceedance of specified limits.

The following are typical examples of steps that could be implemented and described in a recovery plan.

1. <u>Modify Equipment to Reduce Acoustic Noise Emitted</u> - Discuss possible equipment design modifications that could be implemented to reduce noise.

2. <u>Limit Number of Subrack Components Operating Simultaneously</u>

3. <u>Change Equipment Operational Parameters</u> - Examples include change of equipment operating speed, change in operating voltage, etc.

4. <u>Implement Controls with Individual Equipment Developers</u> - At the integrated rack level, one aspect of control is to determine significant contributors to the acoustic noise violation and, as a rack integrator, work individually with the equipment developer(s) to reduce acoustic noise emission.

5. <u>Remove Conservatism using Higher-Fidelity Data</u> - If acoustic noise data is preliminary data incorporating a factor of safety, an early energetic testing program can remove unnecessary conservatism, thus reducing the predicted noise emission.

6. <u>Retrofit Acoustic Barriers to Experiments</u> - Acoustic noise can be reduced by attaching an acoustic blanket or acoustic barrier to the front of the equipment or rack to absorb/block emitted acoustic energy.

7. <u>Reconfigure Integrated Rack to Remove Noisy Equipment</u>

D.5.2 APPROVAL PROCESS

The Payload-Unique Acoustic Noise Control Plan shall be submitted to the ISS Utilization Office, OZ3 per the schedule in Section D.3.2.1 herein. It is reviewed by the ISS Utilization Office and Acoustics Working Group to verify that the planned acoustic noise control and verification plans are adequate to meet specified noise requirements of the IRD and the data needs of the Element Integrator. Review comments/approval will be returned to the developer of the plan within two months after plan submission.

D.6.0 REFERENCES

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4. Int’l. Std. Book No. 0-9622072-0-9, “Noise and Vibration Control”, Revised Edition, Edited by Leo L. Beranek, Institute of Noise Control Engineering, 1988.

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8. ANSI-S12.31, “Precision Methods for the Determination of Sound Power Levels of Broad-band Noise Sources in Reverberation Rooms”, 1996.

9. ANSI-S12.32, “Precision Methods for the Determination of Sound Power Levels of Discrete Frequency and Narrow-band Noise Sources in Reverberation Rooms”, 1996.

10. ANSI-S12.33, “Engineering Methods for the Determination of Sound Power Levels of Noise Sources in Special Reverberation Test Room”, 1990.

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12. ANSI-S12.12, “Engineering Method for the Determination of Sound Power Levels of Noise Sources using Sound Intensity”, 1992.13. ISO 9614-2, “Acoustics - Determination of Sound Power Levels of Noise Sources using Sound Intensity - Part 2: Measuring by Scanning”, 1996.

13. ISO 9614-2, “Acoustics - Determination of Sound Power Levels of Noise Sources using Sound Intensity - Part 2:Measuring by scanning”, 1996.